

Technical Note

An energy-focused thermoacoustic-Stirling heat engine reaching a high pressure ratio above 1.40

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Abstract

A new tapered resonator was introduced in the thermoacoustic-Stirling heat engine (TASHE) to explore its potential of achieving higher pressure ratio. With average pressure of 1.5 MPa and heating power of 3 kW, a high pressure ratio above 1.40 was obtained, which is very beneficial to be a powerful driving source of pulse tube cryocoolers or thermoacoustic refrigerators. Moreover, a relatively low onset temperature of 73 °C was also observed that showed the feasibility of its application in the field of using low quality heat sources.

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1. Introduction

As one of the promising heat engines, the thermoacoustic prime mover is the device that realizes the energy conversion of heat energy into acoustic energy. Of the two known types of thermoacoustic heat engine, i.e., the standing-wave heat engine and the traveling-wave heat engine, the former has been studied more early and more intensively. However, since the latter may overcome the inherent irreversibility of the former, it has much higher thermal efficiency and more application prospect.

Last decade has witnessed the progressing and booming of traveling-wave thermoacoustic heat engines. In 1998, Yazaki et al. successfully constructed a pure traveling-wave thermoacoustic heat engine that demonstrated a better performance than the standing-wave heat engine, but still with low efficiency [1]. In 1999, Backhaus et al. developed the so-called thermoacoustic-Stirling heat engine (TASHE) with thermal efficiency up to 0.30, which is comparable to the conventional internal combustion engine (0.25–0.40) [2].

In 2005, Luo ever reported a new progress with a modified TASHE, i.e., the so-called energy-focused TASHE that achieved a high pressure ratio of about 1.30 with helium [3]. With the energy-focused TASHE, our thermoacoustically driven pulse tube cryocooler and room-temperature thermoacoustic refrigerator have obtained encouraging results [4,5].

As indicated above, a thermoacoustic heat engine with higher pressure ratio may bring about a better performance for thermoacoustically driven cryocoolers, so exploring the energy-focused TASHE with higher pressure has been one of important task in this field. This technical note reports the experimental progress of our new energy-focused TASHE with much higher pressure ratio and much lower onset temperature.

2. Experimental system

The tapered resonator used in our first energy-focused TASHE (EF-TASHE) was not carefully optimized. Therefore, we think that there is still much space to improve the EF-TASHE performance. Recently, we designed a new

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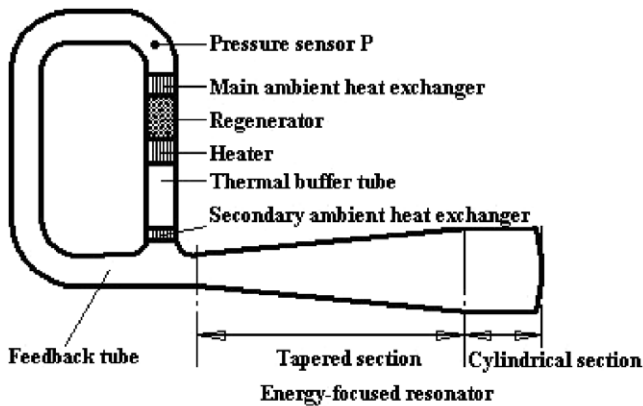


Fig. 1. Schematic of the energy-focused thermoacoustic-Stirling heat engine (EF-TASHE).

Table 1
Dimensions of the two energy-focused resonators

	Previous resonator	Present resonator
<i>Tapered pipe</i>		
Inner diameter of the small side (mm)	80	80
Inner diameter of the large side (mm)	200	300
Length (mm)	4000	5000
<i>Cylindrical pipe</i>		
Inner diameter (mm)	200	300
Length (mm)	500	1000

resonator for our EF-TASHE with the help of computational fluid dynamics (CFD). Fig. 1 shows the schematic of the EF-TASHE system. Basically, the whole resonator assembly is composed of two sections: one is tapered section that is used to eliminate or suppress excitation of high harmonic oscillation modes, and the other one is a cavity with an infinitely large volume, which is used to form a quarter wavelength acoustical system. Table 1 lists the detailed dimensions of the previous and present resonators.

The dynamic pressure was measured by a PCB piezoresistive pressure sensor located at the point *P* where is about 4 cm from the inlet of the main ambient heat exchanger as shown in Fig. 1. In addition, the temperature of the heater was measured by a 1-mm-diameter K-type-thermocouple. It should be noted that the temperature of the working gas itself must be a little lower than the measured temperature.

3. Experimental results

Fig. 2 is the pressure ratio in stable operation at the point *P* for different average pressures and different heating powers. From the figure, it can be seen that the new EF-TASHE achieved a high pressure ratio of above 1.40 with 1.5 MPa nitrogen gas when the heating temperature is about 671 °C and heating power 3.0 kW. One may understand that due to much larger heating power con-

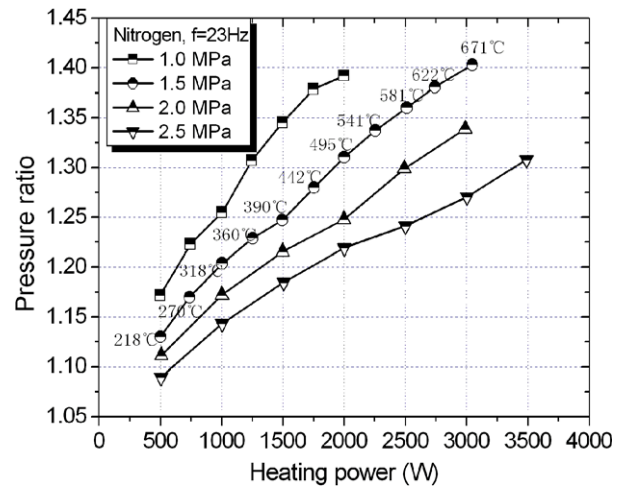


Fig. 2. Pressure ratio vs. heating power.

sumption for higher average pressures such as 2.0 MPa and 2.5 MPa, so their heating temperatures could not reach the same heating temperature of 1.5 MPa operating case. As a result, their pressure ratios did not reach 1.40 when using 3.0 kW heating power. Fig. 3 shows the comparison of the relative oscillating pressure between the old and new resonators, which shows that the new EF-TASHE significantly increase relative pressure ratios. Besides achieving higher pressure ratio, the present resonator also leads to lower onset temperature. Fig. 4 gives the comparison of onset temperatures between the old and new resonators. With nitrogen gas, our previous EF-TASHE has the onset temperatures above 125 °C for all operating pressures, whereas our new EF-TASHE has a relatively low onset temperatures; for instance, for average pressure of 1.5 MPa, an onset temperature of only 73 °C was achieved for the new EF-TASHE. This low onset temperature shows a good potential of the new EF-TASHE in the application of using low quality heat sources such as industrial waste heat and solar energy.

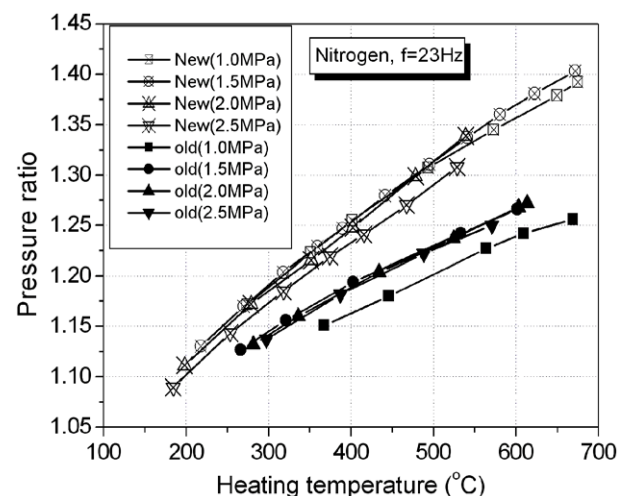


Fig. 3. Comparison of relative oscillating pressure between the old and new resonators.

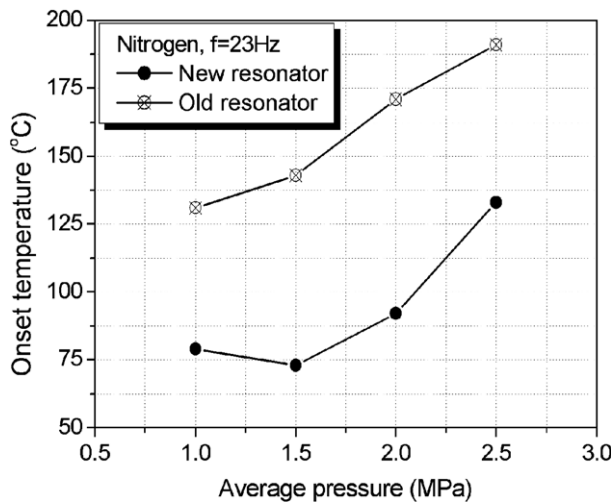


Fig. 4. Comparison of onset temperature between the old and new resonators.

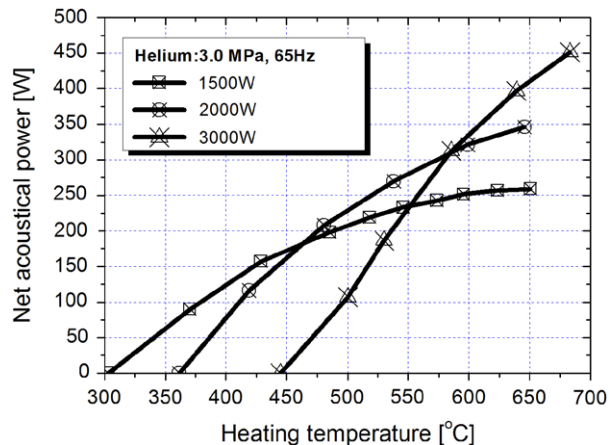


Fig. 5. Net acoustical power output of the old EF-TASHE with helium gas.

In addition, we have also experimentally tested the performance of the old and new EF-TASHEs with helium gas. Fig. 5 presents the net acoustical power output of the old EF-TASHE under different heating powers and heating temperatures. From this figure, one can see that more than 450 W acoustic power can be produced with 3 kW heat power, 671 °C heating temperature and 3 MPa average pressure. Fig. 6 gives the pressure ratio comparison between the old and new EF-TASHE, which also shows the new resonator gives much better performance than the old one. Generally, for the same operating conditions, the new EF-TASHE can increase oscillating pressure amplitudes by 20–30%. According to thermoacoustic theory, the net acoustical power is proportional to the square of oscillating pressure amplitudes, so the new EF-TASHE would output acoustical power with an increase of about 40–60%. At present, detailed measurement of the net acoustic power for the new EF-TASHE has not been finished, which will be left for future work.

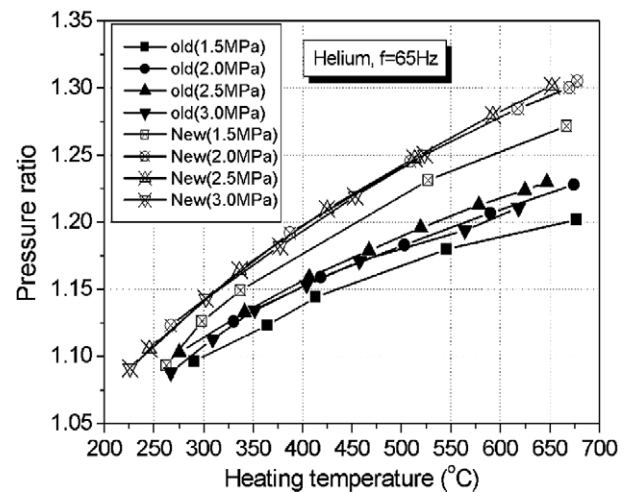


Fig. 6. Comparison of pressure ratios between the old and new EF-TASHEs with helium gas.

4. Conclusion

The research of the new EF-TASHE demonstrated once again that the resonator accounts for one of the main factors that strongly affect the pressure ratio and onset temperature. Thus, properly design a resonator can lead to great improvement of the system performance. In this work, using the new tapered resonator, we successfully achieved a highest pressure ratio of above 1.40 and a lowest onset temperature of 73 °C with nitrogen gas, which are the two records ever reported in the research of TASHEs. In addition, some experimental comparison with helium gas were made, which also demonstrated the new EF-TASHE gives much better performance than the old one. Detailed comparison on acoustic power output between the old and new EF-TASHE will be conducted in near future.

Acknowledgement

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